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Estimating Position and Motion of Mobile Profiled Targets

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Abstract

Sensor observations of mobile time-critical, or "pop-up" targets are typically brief and punctuated by long, irregularly sized invervals. However, maintaining or at least estimating the positions and motions of time-critical targets is of utmost importance for reducing their threat to naval aviators and other naval assets. The TEMMPTS software tool processes data from a variety of sources to determine the regions where time-critical targets are most likely to be found, and thus forms the first link in an estimate-search-destroy chain for such targets. Presented here is an overview of the TEMMPTS project, a description of some of the most important design objectives for the TEMMPTS tool, and a discussion of the work underway to meet those objectives.

1 Introduction

The Real-Time Execution and Decision Support (REDS) prototype under development at Spawar Systems Center, San Diego (SSC-SD) represents a revolutionary mission management concept: a one-step, rapid mission planning, mission rehearsal, and information management package for real-time decision making. The REDS product suite is a response to the U.S. Navy's technological need for accuracy, speed, accessibility, and flexibility in its mission planning process, and it supports in particular the Navy's time-critical strike (TCS) timeline requirements by decreasing the total time consumed in the end-to-end kill chain.

One of the tools being developed for the REDS suite is the Temporal Evaluation Model for Mobile Profiled Targets (TEMMPTS). The TEMMPTS software tool determines those areas within the region of conflict where time-critical, or "pop-up" targets are most likely to be found. This information is delivered by the TEMMPTS tool in terms of a *probabilistic map*, which is a map overlaid with semi-transparent color-coded regions and other annotations indicating where mobile targets are most likely to be located. To generate a probabilistic map, the TEMMPTS system uses raw data from a variety of sources: readings received from airborne and ground-based sensors, map data that describes ground topology, information obtained from available intelligence sources, and target motion tendencies inferred from historical observations.

The targets under consideration here are visible to sensors on occasion, but long periods of time typically elapse between sensor measurements. Targets of this type tend to be mobile or relocatable; that is, they may be capable of moving under their own power, they may be capable of being towed, or they may be weapons that can be taken apart, put

into a heavy equipment transport (HET) or other vehicle, and reassembled in a remote location with relative ease. Significant examples of targets that fall in this class include both mobile erector launchers (MELs) and transportable erector launchers (TELs). Thus the probabilistic maps generated by the TEMMPTS system can be thought of as the first link in an estimate-search-destroy chain for time-critical targets.

The data sources available to TEMMPTS determine to a large extent the form that the final system will take. As with practically any type of sensor, considerations for false alarms and missed detections must be incorporated into the systems design; this is especially true for the TEMMPTS system which is expected to depend on sensors that may be cheap and thus plentiful, but also noisy. The TEMMPTS design has to accommodate data that arrives at irregular times, because data may in some cases be provided only when a target is emitting RF energy.

The TEMMPTS tool exploits the fact that the topology of the ground in the region of the target can impose significant constraints on the motion of that target. For example, targets may be unable to travel over grades steeper than, say, 10%. Thus, information about ground topology, obtained from NIMA data sources, for example, will provide important clues about the regions where a target could have moved since its position was last fixed. Intelligence information can also provide significant insight into the expected location and behavior of mobile targets, and the TEMMPTS system will have the capability to incorporate into its estimates of target position the logical consequences of information obtained from intelligence sources.

First-year prototyping is being carried out in MATLAB with data feeds to be provided by JSAF or a JSAF-like simulator. Second-year work will focus on porting from MATLAB to JAVA, and refining the algorithms and human-machine interface to ensure maximum utility and robustness. The third-year of the effort will focus on live data feeds and integration of the TEMMPTS system into the REDS/RTR distributed computing environment. The third-year effort will also consider how the TEMMPTS system could integrate and exploit specific-emitter identification (SEID) technology.

The remainder of this paper is organized as follows. Section 2 discusses how incoming sensor readings are used, when they are available, to generate a high confidence estimate of the positions of targets. Section 3 deals with determining the area over which a target could have moved since its position was last fixed. Section 4 talks about the integration of geopolitical tendencies, historical data, and intelligence information will be used to refine the estimates made by the TEMMPTS tool. Section 5 provides a summary of key points.

2 Estimating Target Position

Estimates of target locations are generated using Baysian analysis, and incorporate techniques developed in [Hespanha, 2001] to deal with joint probabilities that would otherwise become unwieldy for even a moderate number of targets.

The position of a target is taken to be a random variable, and the readings returned by a sensor are also treated as a random variable, because noise within the environment and within the sensor itself will cause the sensor on occasion to report a target when there is in fact none (false alarm), and also to report no target when one is in fact present (a missed detection). The assumption that a sensor delivers noisy measurements gives us the greatest leeway in accepting data from a wide variety of sensors.

Our approach uses Bayesian analysis to work backwards through coupled probabilistic events, in much the same way that it is used in a radio receiver to decide on the value of a random variable sent by a transmitter [see, for example, McDonough, Ch. 5]. That is, just as a digital radio receiver has to use a signal corrupted by the channel to determine whether a 0 or a 1 was sent by the transmitter, the TEMMPTS system has to use noisy sensor data to determine whether a target is, or is not, present at some small region of ground. More specifically, we are given the sensor readings, and we have to make an estimate of the target position. More formally, we have to figure out $p(t \mid s)$ when we have on hand values for $p(s \mid t)$. Bayes theorem is the key to working this "reverse" problem- it allows us to estimate the value of a random variable like target position using a related random variable such as a sensor reading. Furthermore, the Bayes formalism allows us to incorporate probabilistic information that is available before any sensor measurements have been made, the so-called *a-priori* information.

In concept, the ideas outlined above are very straightforward. In practice, however, we have to deal with the complication that we cannot expect the positions of targets to be independent, and the joint probability functions describing even a moderate number of targets can become unmanageably large. To illustrate this complication, suppose that our region of interest is a two-dimensional surface partitioned into a (very coarse) grid of 10x10 blocks. Suppose further that 20 mobile targets are distributed throughout this grid. If the targets are distributed independently of each other, then each of the 100x99x98x…x81x80/(20!) ~ 5x10^20 possible configurations are equally likely. However, it is unlikely that the targets will be distributed independently- for example, SAM launchers would probably be distributed with their radar coverage areas overlapped slightly, and configured to form a barrier that would have to be penetrated to reach a high-value target. Any direct approach to assigning appropriate *a-priori* probabilities to each such configuration would be impossible in a practical sense.

This complication is being approached through the use of aggregate measurement functions [Hespanha, 2001], which allow the a-posteriori probabilistic map (that is, the probabilistic map which incorporates information from sensor measurements) to be represented as a simple function of the single-emitter sensor likelihood function. In order to make this simplification, it is necessary to assume that (1) the emitters are indistinguishable from each other; and (2) the sensor can only be within range of at most one emitter at a time.

3 Constraints on Target Motion Due to Terrain: Dilution of Precision and the Maplet Concept

The discussion above indicates how sensor readings can be used, when they are available, to estimate the position of potential targets. In this section we discuss how information about the terrain conditions in the vicinity of the target can be used, along with information regarding the targets ability to traverse different terrain types, to determine where the target could have moved in those times between sensor measurements.

Conceptually, new incoming sensor readings can be thought of as causing a broad, shallow probability density function (PDF) for target position to constrict, or collapse, to cover a relatively small spatial region with high density. As the sensor measurements which caused the collapse grow older, the location of the mobile target becomes less certain, and the PDF describing its position dilates, or spreads out, and grows shallower. We borrow a term from the radio-navigation community and refer to this broadening and shallowing of a target position PDF as *Dilution of Precision (DoP)*.

Our current approach to computing the DoP for a given target takes the following form. From NIMA VMAP Level 0 or other sources, we extract feature information such as locations of roads, locations of waterways, and ground cover types, that will have an effect on the motion of the target under consideration. Each of these data sets is then projected individually onto the cells of a fine array (say 2000x2000). The resulting numerical grid, which we call a *maplet*, contains a scale factor in each feature cell which gives that features effect on the normal, or base-velocity of the mobile target being considered; other cells contain a 1. For example, we may know from a platforms profile, that a certain type of ground cover cuts that platforms velocity to 80% of its normal value; in the corresponding ground cover maplet, cells that contained that ground cover would contain the scale factor 0.8, while all other cells in that maplet would contain the value 1.

In use, maplets are multiplied together cell-by-cell, so that an estimate of the average velocity of the platform while it is within that cell is obtained. From this map of average velocities, the total amount of time required for the platform type to traverse a given cell from edge to opposite edge is then associated with the cell. From an initial position determined using the method of Section 1, the cells that the platform could have crossed as simulated time increases are determined.

A number of issues associated with this algorithm are being investigated at the present time. The use of maplets allows the scale factors for different platforms to be changed easily, because the interactions between terrain information and platform information are very minimal. Of course, there is an obvious tradeoff between the number of cells in the map grid, and the accuracy, time, and memory requirements associated with the final result.

Of particular significance is whether the technique used for determining the effect of multiple terrain features on velocity is reasonable. The approach outlined above essentially treats the influence of each different type of terrain feature as independent, so that, for example, the retarding effect of muddy soil and the retarding effect of passing through a field of saplings are simply multiplied together to find the retarding effect of traversing a field of saplings in muddy soil.

4 Refining Estimates using Geopolitical Tendencies and Intelligence Information

A potentially significant source of information for estimating target position and motion is contained in historical data. It may have been observed, for example, that when some given country is in a particular readiness state, mobile targets tend to move in certain characteristic ways. Such information could significantly influence the estimates made by the TEMMPTS tool. However, the literature seems to indicate few (if any) cases in which symbolic policy and intelligence information has been converted into a computational form appropriate for fusion into a probabilistic map. Motivated by the large value that this information may have on target estimation, we are investigating computational models to represent geopolitical behaviors and historical tendencies.

Similarly, inteligence data available about the area of conflict may contain valuable information about the locations and motions of mobile targets. However, if the amount of available intelligence information is very large, it may be impractical to fully exploit it simply because of its size. Natural Language Processing (NLP) techniques have been used sucessfully in a variety of applications (see for example [Rowe, 1994], [Michael et al, 2001]), and we are investigating whether it could be used to extract information about target positions or motions from plain-text intelligence information. The use NLP techniques for extracting information from plain-text intelligence information holds promise because, although the syntax associated with statements of target positions and motions is expected to be roughly as complex as that of any other type of plain text, the semantics are expected to be relatively uncomplicated.

5 Summary

The TEMMPTS software tool generates estimates of the position and motion of mobile profiled targets, and will form the first link in an estimate-search-destroy chain for such targets. With TEMMPTS and the REDS mission managemeent system, the warfighter will realize an increased ability to respond to changing battlefield and operational conditions, and real-time mission repair, re-planning, and retargeting of in-theater assets will be achieved.

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